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A New Model for Impulse Noise Distribution Resulting from Digital Apparatus

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ABSTRACT

This paper proposes a new model which describes a radiative impulse electromagnetic noise distribution resulting from a digital electronic apparatus.

An electronic apparatus is supposed to be composed of multiple cavities and the impulse noise is replaced by a flux of corpuscules diffused and scattered by these cavities. A subject of this research is to know how much the discrepancy between a result from this model and the real impulse noise distribution is.

Preliminary results of the model verification experiment are shown.

Key Word: Electromagnetic Compatibility

1. Introduction

Digital devices have come to be used in wide and various fields. However, many digital devices have an unfavorable nature by which an electromagnetic noise is radiated to its environment. Therefore a structure which does not radiate an electromagnetic noise to the outside from itself is desired. Moreover a structure of which an electromagnetic noise from the outside does not invade into device is needed. In the undergoing practice, a trial apparatus, first of all, is tested for EMI standard. In case when the EMI level is out of the tolerance, the redesign which strengthens it is made up. But this circuitous process should be improved more simply because a tremendous cost is then required.

To solve this problem a method by which the intensity of a radiative electromagnetic noise is judged quantitatively beforehand must be developed promptly. Generally there are two kinds of a conducting noise and a radiative noise in an electromagnetic noises regarding digital devices. The former is the one which comes through the power supply line, and the latter is the one which propagates through the air. A transmitting route of a conducting noise is so simple as has been known well that the characteristics have already been solved fairly precisely.[1)] Contrary to this, a spread route of a radiative electromagnetic noise is so complex that an analysis of the characteristics is still difficult to be described. Up to the present, it has been analysed through a method of trial-and-error, and experience. However, the setting of complex and troublesome boundary condition is needed when Maxwell's equation regarding an electromagnetic field is applied in this theoretical analysis.

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Moreover, it is very difficult that it is analysed because the active elements used in the apparatus have a nonlinear characteristic. By this reason the authors do not adopt the method mentioned above. A mode introduced here regarding the electromagnetic noise resulting from a electronic apparatus is made from a phenomenal viewpoint. After all, the authors try to study the electromagnetic impulse noise resulting from digital electronic apparatus on a viewpoint of a flux of corpuscles.

At first, the authors selected a computer as the object for our research. Main measuring instruments for a noise radiated from the devices are a magnetic field meter and a spectrum analyzer. Our first item of the measurement is to analyze frequency characteristics of a radiative electromagnetic noise. From these measuring results it is found that many impulse noises with a line spectrum are distributed up to about 450 MHz ranges for a main frame-computer, and about 250 MHz for a microcomputer.[2)3)] In this paper, the subjects of our research are to propose a model of a flux of corpuscules, and after that, to make it clear experimentally that the model is effective to analyze these impulse noises.

2. Electromagnetic Impulse Noise

2.1. A Tentative Consideration for Electromagnetic Noises

An impulse electromagnetic field is radiated to the outside from a part of the wave head of stepwise current driven in a system by a digital element.

An energy of the electromagnetic impulse radiated at one time from a noise source is considered to be the same. When only linear media are concerned, the electromagnetic impulse does not interfere mutually.

The authors suppose that electronic apparatus in **Fig. 1** are composed of transmission lines of conductor, loop, metal fragments and those combinations of these. They are radiated once again, after a part of a radiative electromagnetic impulses is captured by this cavity. They are scatters. Several cavities absorb the electromagnetic energy into the inside. Or the waveform and frequency of pulses change, because they have nonlinear nature.

Also, because they have a parametric action, they exchange the electromagnetic energy between each other. If the size of an electronic device regarded as an object is sufficiently small, the process becomes in the steady state enough quickly in comparison with an existence period of an electromagnetic pulse.

2.2 A Model with Possion's Equation

This electromagnetic impulse is a wave by nature. Then a flux of wave discharged according to the change of H→L or L→H of a digital signal source is thought to be a electromagnetic impulse.

Thereupon, an intensity of an electromagnetic impulse is equal to the total sum of particles. The intensity observed should be defined as the number of particles which passes through an unit area every in an unit time. The speed of a particle is the velocity of light, c. From the above considerations an intensity of an electromagnetic pulse is expressed by a flux of corpuscules of an electromagnetic noise (1).

$$\phi = \tilde{\phi}(\vec{\omega}, \vec{r}, t) \tag{1}$$

This flux has the functions of a motion direction $\vec{\omega}$, place $\vec{r}$, and time t.

In the case when motions of many particles group are shown with a equation, kinetic energy, $E=1/2mv^2$, is regarded as an independent variable generally. However, because it is supposed that every velocity of cluster is equal to the one of light, it does not appear explicitly. If kinetic energy is treated as one component, this particle is able to say to be a so-called photon. But the authors do not adopt such idea here.

A distribution of particle flux (1) should be expressed by a transport equation which is still difficult to be solved. This is not consistent with the object to concisely *express a field of an electromagnetic impulse.* Therefore the authors solved to coverage the flux $\tilde{\phi}$ over the all directions.

$$\phi = \frac{1}{4\pi}\int_{\Omega} \tilde{\phi}\, d\vec{\omega} \tag{2}$$

If the balance is kept about the number of the particles which go in and out among every an unit time from an unit volume by supposing like this, a diffusion equation of an energy (3) is obtained.

$$-D\nabla^2 \phi \ (\Sigma_a - \Sigma_f)\phi = S \tag{3}$$

The first term of the left side of this equation is an amount lost by a motion of a particle. D is a constant of a diffusion constant. When a space density of a cavity is high, the larger a scattering sectional area is the better effect this term becomes. The second term of this equation is an amount of the particles which disappear by capture.

Here Σ_a stands for a macroscopic sectional area of absorption. And Σ_f shows the macroscopic sectional area which stands for an amplification. Many amplifying elements are used in an electronic apparatus. Actually many particle are discharged more and more even when particles are absorbed. As has been described, this equation does not depend on time. This thought is understood that this equation shows the average value over some periods

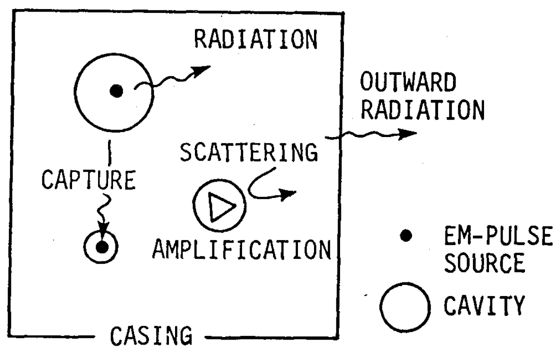

Fig. 1 A Model for Electromagnetic Impulse Noise in Electronic Apparatus

and if phenomena of an electromagnetic impulse is a perfect probable process, it is expected that this formula is exact at the same time in addition to an Ergotic Hyphothesis.

2.3 Boundary Condition

A boundary condition of a particle system is more complex than one of an electromagnetic field. A flow of a particle is expressed with the following equation:

$$J = -D\Delta \tilde{\phi} \tag{4}$$

Here there are two flows, which inpinge to the wall vertically, and reflect from it as

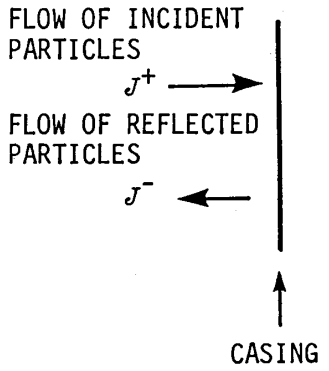

Fig. 2 Boundary Condition

and a flow on the boundary face is obtained.

$$\frac{1}{\phi} D\nabla\phi = -\frac{1}{2}\left(\frac{1-\alpha}{1+\alpha}\right) \tag{5}$$

Here α is a reflecting ratio (Albedo), which is shown in the equation (6).

$$a = J^- / J^+ \tag{6}$$

2.4 Solution for One Dimensional Case

In order to illustrate a feature of a solution of a diffusion model, a slab geometry which spreads only to the x direction limitedly and uniformly to the y and z directions finitely is made. Now if a noise source exists only in the position of $X = X_1$, a solution of equation (3) is written as (7), (8) and (9), vig,.

$$\phi = \phi_1 \cosh\frac{x - x_1}{L} \mp \frac{J_1^{\pm}}{D} \sinh\frac{x - x_1}{L} \tag{7}$$

$$L = \sqrt{D / (\Sigma_a - \Sigma_f)} \tag{8}$$

$$J_1^+ + J_1^- = S \tag{9}$$

Φ_1 and $J_1^{\pm}$ are decided by the boundary condition (5) of $X=0$ and $X=X_B$. And the suffix complies with $x \lessgtr x_1$. An example of this solution is shown in **Fig. 3**. At a domain of $\Sigma=$

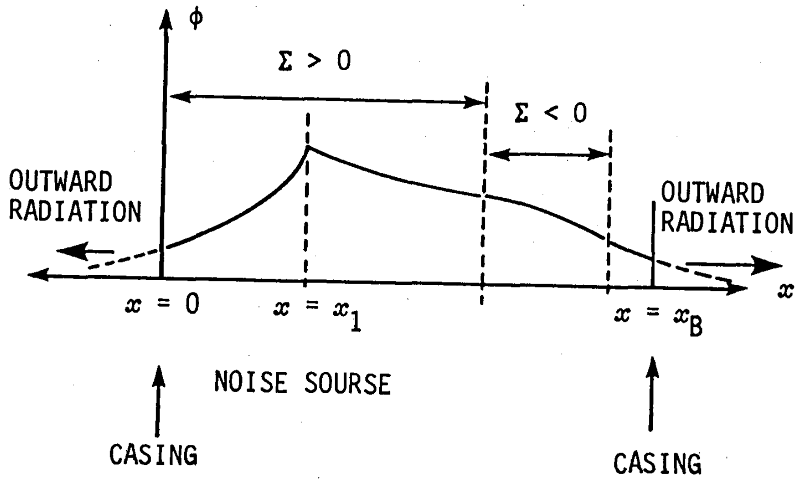

Fig. 3 Distributions of Flux of Corpuscule from a Film-shape Noise Source

$\Sigma a - \Sigma f > 0$, distribution of ϕ is convex, and then at a domain of $\Sigma < 0$, concave.

2.5 A Concept of Importance

It is supposed that there is a distribution ϕ of flux of a noises in a vessel. The authors investigate how a distribution of a new flux $\phi' = \phi + \delta\phi$ changes, after a small absorbing body $\delta\Sigma_a$ is brought in here. If the higher terms than the second are neglected, the equation regarding the deviation becomes (10). A form of the left side is perfectly the same with (3). When a source of $-(\delta\Sigma_a)\phi$ exists, the right side agrees with this formula.

$$-D\nabla^2(\delta\phi) + (\Sigma_a - \Sigma f)(\delta\phi) = -(\delta\Sigma_a)\phi \qquad (10)$$

After all, if a medium of the same macro-sectional area is brought in here, the highest effect is obtained in the largest place of a distribution of a flux of corpuscules. A distribution of this ϕ is named "*importance.*"

3. Experiments

3.1 Method

The model described above is an idea which does not depend perfectly on a experiment. Therefore it is not able to be judged by this discussion alone whether or not this idea is correct. So the authors try to examine the availability of this model by using the real electronic apparatus. The objects to be measured is a flux of impulse electromagnetic noise, ϕ. A probe used to detect it is a shield loop antenna connected to a rigid coaxial cable shown in **Fig. 4**.

Because the dimension is small in comparison with the wave length, the internal impedance is inductive completely, and the gain to the magnetic field is proportional to the frequency. Therefore a real magnetic field intensity cannot be directly measured by this. On the model described here only a power density is considered neglecting a frequency. The authors consider this small antenna as a cavity which has a sectional area of scatter and capture

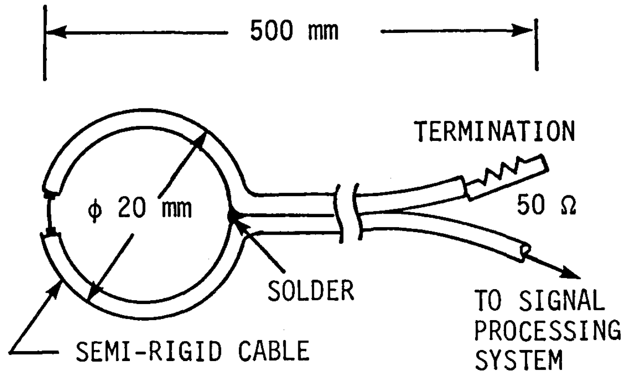

Fig. 4 Electromagnetic Field Probe

brought in from the outside. Only flux of the relative distribution is concerned.

To measure the power of an electromagnetic field, squaring operating computation should be carried out for the voltage or current output in a electromagnetic field probe.

Echigo et[4] reported that though he tryed to connect a diode to a loop antenna directly and measure DC current, it could not attain the initial purpose to measure DC output for the interference of the existence of its nonlinear capacity.

And Hayashi et[5] reported us that the output light was taken out through an optical fiber by using the LED with DC bias.

To avoid these risks, the authors carried out a square detector as precisely as possible with IC square multiplier for the preamplified antenna output.

A schematic of the measurement system is shown in **Fig. 5**. The output of the loop

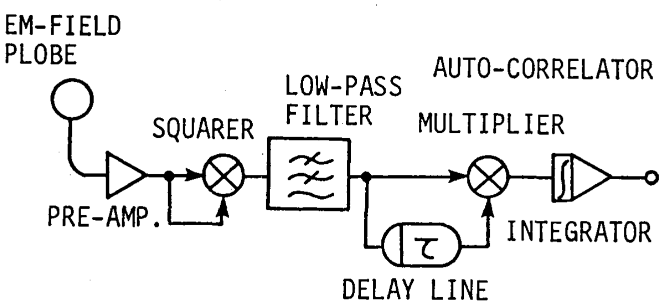

Fig. 5 Schematic Construction of Measuring Electromagnetic Impulse Noise

antenna through a preamplifier is squared by IC amplifier. The output through a buffer amplifier which has a role of a low pass filter is calculated by other IC multiplier equipped without a delay line. It gives a autocorrelation function. The statistic of the generation of the noise particles described by the autocorrelation function.

3.2 IC Multiplier

Using a IC multiplier (MC 1459, Motorola Co.) and a differential amplifier, HA2525, the output is amplified. Frequency response of this multiplier as a squarer is shown in **Fig. 6**. The test signal was amplitude-modulated by 10 kHz sinusoidal signal to 30% modulation coefficient. The output was read by a spectrum analyzer.

A bandwidth of frequency with 10 kHz component of 3 dB among the output is 55

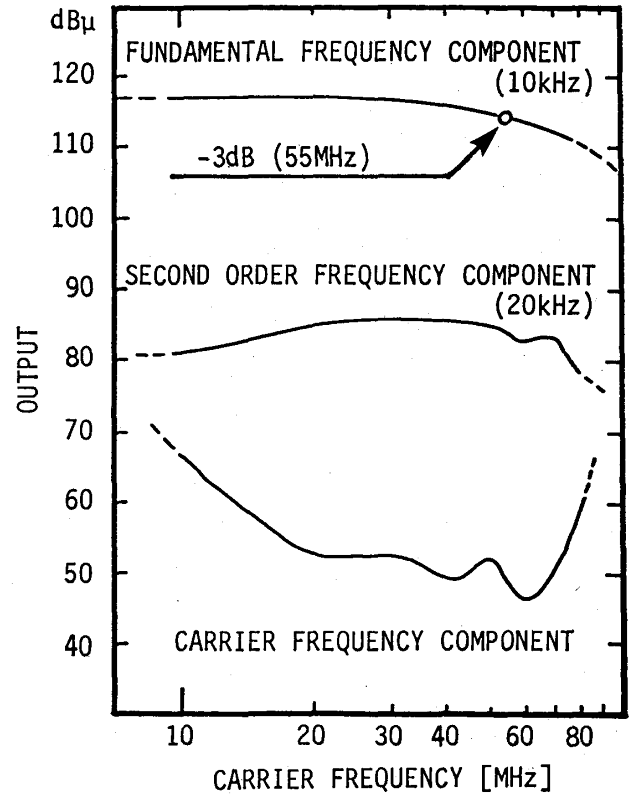

Fig. 6 Frequency Characteristics of Squarer used as Multiplier

MHz. The maximum input voltage which maintains lineality is about 100 mV. This band width is insufficient for radiative electromagnetic field from the microcomputer described previously. This preliminary measurement is carried out. The multiplier which has a enough wide bandwidth will be developed hereafter.

3.3 Delay Circuit

An oscilloscope delay line of Tektroniks Co. and a DEC-10-20 of TDK Co. used as a digital circuit are adopted. A total delay time of the latter is 100 ns. It has a tap at every 10 ns. A characteristic impedance is 200Ω. A frequency band width is about 10 MHz. It was calculated experimentally that an enveloping curve of a radiation electromagnetic field radiated from microcomputer can be treated by both of these elements.

4. Results of Experiments

The authors adopted about a computer used for developing a system as a measuring object. This computer is based on with Z80 as the CPU, a system composed of some units of TTL of a clock frequency 4 MHz, and the casing of 0.5 mm thick iron sheets.

A back panel is removed to insert a prove into the measurement. Data of **Fig. 7** is the one whose an output waveform of a squarer was recorded by a digital oscilloscope. A loop antenna was put adjustment to the CPU. A strong radiative pulse is recorded every about 2 μs in Fig. (a). The data in Fig. (b) is the one on the longer interval than in Fig. (b). An arising is found because the sampling period is far wider than the clock in this figure.

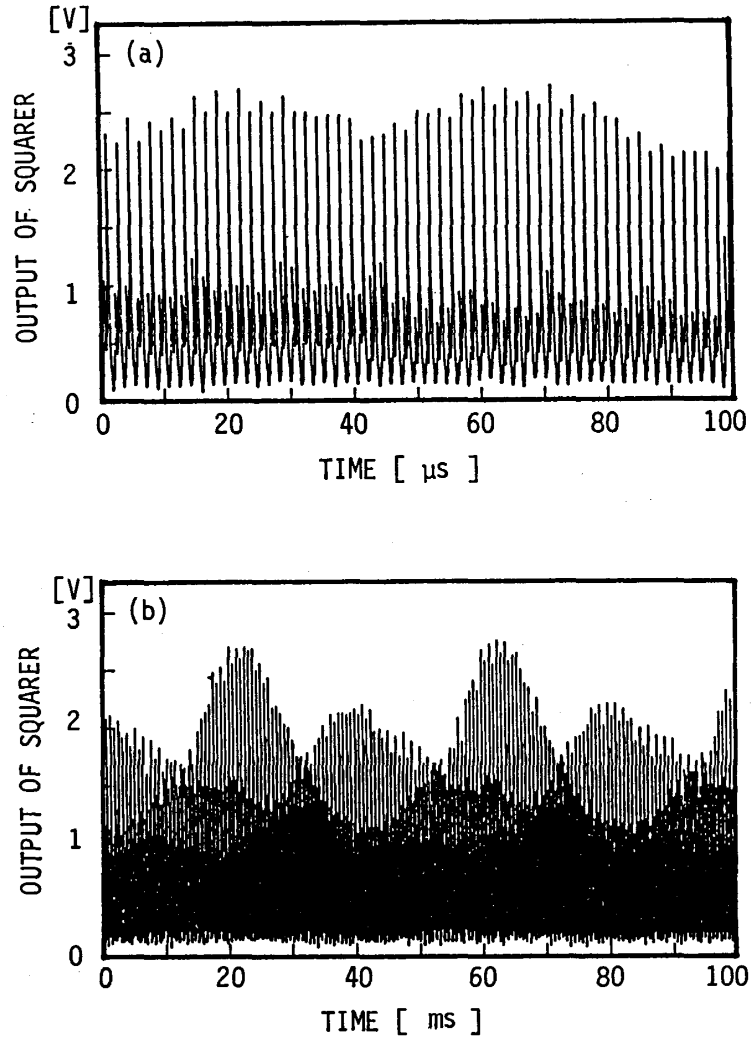

Fig. 7 Waveform of Magnetic Power near to CPU

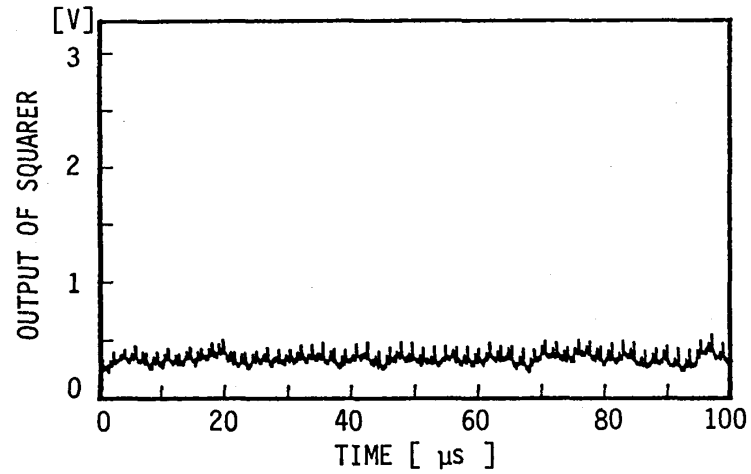

Fig. 8 Waveform of Magnetic Power near to Vessel

Next the result in **Fig. 8** was obtained near the inside of vessel wall. Then the level is dropping. In **Fig. 9** an autocorrelation function of ϕ near the CPU is recorded. A delay time is controlled by changing taps. Fig. (a) is the one when a program runs. Fig. (b) is in a halting state. It is understood very well from those data that a pulse is occurring as

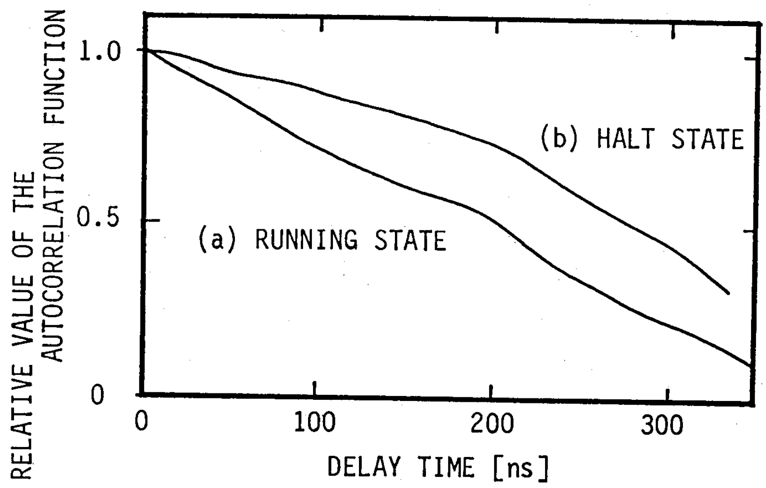

Fig. 9 Self-Correlation of Magnetic Power near to CPU

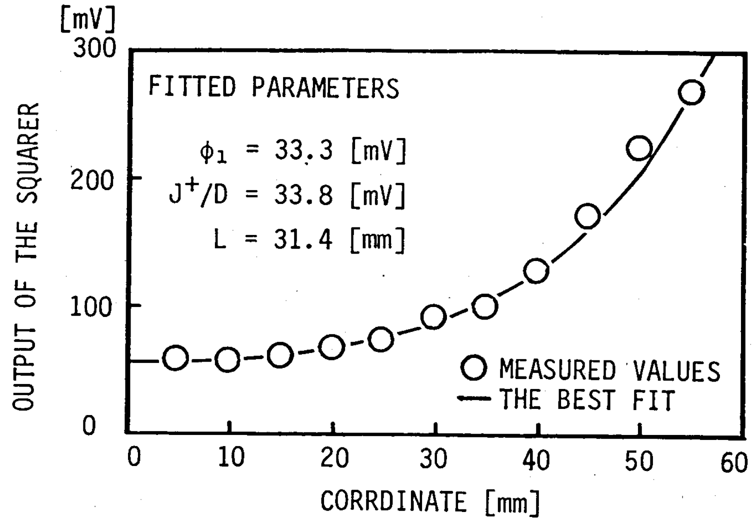

Fig. 10 Measuring Results

a flux.

Next an output voltage of a squarer was measured by changing a position of CPU board in a vessel.

Fig. 10 shows the results. A solid line of this figure is the one whose function is the least square fitting. It is understood that the results by the experiment and theoretical equation are agreed very well beyond the authors expectation.

5. Conclusion

A new model by which a distribution of impulse magnetic noises inside a digital electromagnetic apparatus is able to be described is proposed. But as experimental system used at present has not a sufficient bandwidth for the final object of this research, it should be improved. Furthermore, the authors have the schedule to expand a band width of measurement to 500 MHz by a development of a multiplier of better performance.

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